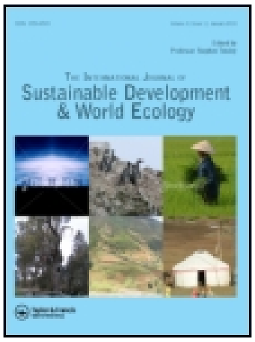

International Journal of Sustainable Development & World Ecology

ISSN: 1350-4509 (Print) 1745-2627 (Online) Journal homepage: https://www.tandfonline.com/loi/tsdw20

A measure of sustainability of Brazilian agribusiness using directional distance functions and data envelopment analysis

Carlos Rosano-Peña, Patricia Guarnieri, Vinicius Amorim Sobreiro, André Luiz Marques Serrano & Herbert Kimura

International Journal of Sustainable Development & World Ecology, 2014
Vol. 21, No. 3, 210–222, http://dx.doi.org/10.1080/13504509.2014.901992

A measure of sustainability of Brazilian agribusiness using directional distance functions and data envelopment analysis

Carlos Rosano-Peña, Patricia Guarnieri, Vinicius Amorim Sobreiro*, André Luiz Marques Serrano and Herbert Kimura

Department of Management, University of Brasília – UNB, Campus Darcy Ribeiro, Federal District, Brasília, 70910-900, Brazil

(*Received 29 October 2013; final version received 3 March 2014*)

The social and environmental impacts caused by the modernization of Brazilian agribusiness have evoked a growing interest in the search of balance between social-economics development and the adequate use of natural resources, driving the country to sustainable development. Therefore, the main aim of this article is to estimate a set of indicators of relative efficiency in the Brazilian agricultural sector, which satisfy the concept of Pareto optimality, potentiates simultaneously both economic, ecological dimensions and social functions. To reach this purpose, the method of directional distance functions and data envelopment analysis was applied. These indicators confirm, in different ways, the hypothesis that it is possible to perform consistent productive strategies with the maximization of social welfare, despite the apparent antagonism among these three dimensions. In addition, it is shown that efficient Brazilian states tend to combine the three dimensions in different ways. Hence, it can be concluded that several equilibrium taken sustainable can be achieved through different actions on poverty and environmental impact reduction without necessarily generating productive inefficiencies. This result can be considered of prominent importance for sustainable development in Brazil and can also serve as a reference in the definition of goals of the plan 'Brazil without Misery' and international commitments to reduce Greenhouse Gas – GHG – in Brazil, especially for the 17 inefficient Brazilian states.

Keywords: Brazilian agribusiness; data envelopment analysis; directional distance functions; sustainability; sustainable development

1. Introduction

The process of modernization of the Brazilian agricultural sector started between 1950 and 1960 (IBGE 2006). This transformation was strongly induced and subsidized by the government and involved the combination of extensive and intensive methods of production, including the expansion of the agricultural frontier and the rapid spread of technological innovations (IBGE 2006). As a result, the agricultural sector in Brazil presented a qualitative leap in the following years, with direct or indirect implications to all participants of this productive chain.

Because of the worldwide growing demand for agricultural products, Brazil had to broaden the scope of its historic concept of familiar agriculture, adopting a market-driven agribusiness concept and creating the roots for the Brazilian agro-industrial complex. Therefore, the modernization process that began in the middle of the last century transformed the Brazilian agricultural sector, turning the country into one of the leading producer and exporter of food in the world. According to the Food and Agriculture Organization (FAO) of the United Nations (UN), Brazil ranks as a Top 5 producer in, for instance, cereals, coarse grains, oil crop, root and tuber, fruit, fibre crop, etc. (Food and Agriculture Organization 2013).

It is important to highlight that the modernization process of the Brazilian agriculture was exclusionary, mainly because it primarily focused on large-scale production, directing efforts to emerge the country as a commodity producer, and eventually compromising the competitiveness of family farms. Small producers were relegated from credit to rural development and from technical assistance. This fact occurred even though family farms were more numerous and produced approximately 70% of the food basket in Brazil (IBGE 2006). Some studies show the rising of the Gini index related to land concentration from 0.83 to 0.85 in the 1940–1980 period (Alcantara Filho & Fontes 2009). In 2008, the index remained at 0.85, and the proportion of the total area occupied by the 50% smaller agricultural enterprises was equal to 2.2%, while the 10%, 5% and 1% larger enterprises comprised, respectively, 79.4%, 69.1% and 41.9% of the total area (Hoffmann & Ney 2010). These numbers embody a great deprivation of basic infrastructure in the agricultural field, including education, health, water access, sanitation, roads, electricity, security, and explain the high level of rural poverty, the migration of population to urban areas and misery in the suburbs of urban centres in Brazil. In 2009, even though Brazil had made some important changes to alleviate social and economic problems, 33% of the rural population still lived in poverty and 14% in extreme poverty (Grossi 2011).

There are also concerns regarding the excessive use of fertilizers and pesticides in the Brazilian agriculture and the environmental impact of the growing number of livestock.

*Corresponding author. Email: sobreiro@unb.br

A study from Food and Agriculture Organization (2006) draws attention to the impact that the development of agriculture has in deforestation, loss of biodiversity, pollution, depletion of water resources, desertification and soil erosion, as well as, in emissions of Greenhouse Gases (GHG), which are blamed to cause climate change and increase vulnerability of activities in agriculture.

Between 1990 and 2005, emissions of GHG in Brazil increased by 62% (Lima, Pessoa, et al. 2010). Approximately, 58% of the 2.2 billion tons of CO_2 equivalent emitted in 2005 in Brazil corresponds to activities related to changes in the use of the area reserved to forests, mainly due to deforestation and fire, and 22% to agriculture and livestock farming, which are expected to increase to 30% by 2030 (McKinsey & Company 2009).

Since some social and environmental impacts of agribusiness modernization can be considered negative externalities, it is relevant to consider not only the inputs and outputs with observable market prices, but also the undesirable, sometimes, intangible outputs, when assessing the modernization of the Brazilian agriculture. An economic sector that fosters sustainable development must simultaneously meet the needs of all stakeholders, finding a balance and a synergy of forces to mitigate risks and to reduce negative impacts to society.

Because of the importance of the Brazilian agribusiness sector not only for the country's development, but also for the worldwide supply of food, and to the perverse externalities, there is a growing interest in the search for balance between socio-economic development and the proper use of natural resources to pursue sustainable agribusiness in Brazil. Therefore, this study aims to analyse *the Brazilian agribusiness sector considering economic, ecological and social dimensions, according to non-exclusive attributes of productivity, equality and environmental responsibility.*

The main objective of this article is to identify a set of indicators of relative efficiency in the Brazilian agricultural sector, which, by following the concept of Pareto optimality, allows the simultaneous enhancement of economic, ecological and social dimensions. The research focuses on the directional distance functions (DDF) method within a data envelopment analysis (DEA) framework, using the latest available data from the Brazilian agricultural census (IBGE 2006) at the state level. The study adds results to the scarce empirical research on socio-environmental efficiency in the Brazilian agriculture.

The research follows the theme of previous studies that evaluate eco-efficiency in Brazil including Gomes and Lins (2008) and Leal et al. (2012), but differs in one important aspect. While the previous studies analyse efficiency solely from the environmental and economic perspectives, the current research assesses efficiency including rural poverty as an inalienable pillar of sustainability in emerging markets (Fredericks 2012; Hansmann et al. 2012; Ali 2013; Cosyns et al. 2013; Lyytimäki et al. 2013). The set of workable indicators shows that the method can be an interesting alternative to operationalize the concept of sustainability and can be used to support the formulation of policies consistent with the maximization of social welfare in developing countries. Consequently, this research also presents evidence of potential improvement of sustainability in the Brazilian agribusiness.

Besides this introduction, this article is structured as follows. In Section 2, the manuscript presents the literature review, discussing concepts of sustainability and studies that use DEA to analyse this theme. In Section 3, the theoretical framework to identify the environmental efficiency is detailed. Section 4 describes the parameters and units of analysis of the environmental efficiency of the Brazilian agriculture. In Section 5, results of the research are discussed. Finally, in Section 6, the main conclusions and limitations of the study are presented.

2. Review of literature

The theme of sustainable development comes in vogue from the report of the Club of Rome entitled 'The Limits to Growth' (Meadows et al. 1972). The report pointed out that the planet would not support socioeconomic growth even taking technological advances into account, owing to the problems related to energy generation, natural resources depletion and increasing pollution. The United Nations sponsored a series of worldwide conferences and commissions to discuss sustainability of the planet, seeking for compromises and solutions. In the Brundtland Report (WCED 1987), entitled 'Our Common Future', a formal definition for sustainable development was established.

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs The sustainable development seeks to meet the needs of the present generation without compromising the ability of future generations to meet their own needs, which means enabling people now and in the future, to achieve a satisfactory level of social and economics development and, human and cultural fulfilment, making at the same time, a reasonable use of land resources and preserving the species and natural habitats. (WCED 1987)

Regarding this definition, Elkington (1998) proposed the concept of the 'triple bottom line' of sustainability, which is the triangulation of People, Planet, Profit, and considers seven dimensions of transformation that must occur to achieve harmonization among economic factors, environmental quality and social justice. Environmental and social problems most severely affect the vulnerable population of developing countries; however, there is yet a scarcity of research related to these regions (Seuring & Gold 2013).

Jabbour et al. (2012) highlighted that manufacturing strategy affects a company's environmental impact, which becomes relevant to analyse the relationship between environmental and operations management issues. In addition, many companies have tried to demonstrate its proactivity by implementing sustainability practices, which aim to monitor and control the impact of its operations on the environment (González-Benito & González-Benito 2008).

In this context, Montabon et al. (2007) state that companies can control their environmental impact by implementing operational, tactical and strategic level practices. The same authors found that good environmental practices imply a positive effect on firm performance. Seuring and Gold (2013) suggest the integration between environmental and social issues into approaches such as multi-criteria decision-making or optimization models as a trend for future research.

Several other approaches appear in the literature to empirically assess the concepts proposed by Elkington (1998). For instance, the study from Heyder and Theuvsen (2012) is based on a survey that explores social and environmental dimensions of 170 agribusiness enterprises of small as well as large multinational corporations in Germany. Claver et al. (2007) studied the connection between environmental management and economic performance from a perspective that includes the relationship between environmental strategy and firm performance. Govindan et al. (2013) examined the problem of identifying an effective model based on the Triple Bottom Line (TBL) approach (economic, environmental, and social aspects) for supplier selection operations in supply chains by presenting a fuzzy multi criteria approach.

In addition, several papers propose the construction of multidimensional indicators of sustainability to evaluate the performance of the agribusiness productive system. Some of these studies can be highlighted: Bockstaller and Girardin (2003), Morse et al. (2001), Munda (2005), Calker et al. (2006), Böhringer and Jochem (2007), Qiu et al. (2007), Speelman et al. (2007), Bauler (2012) and Bojacá et al. (2012).

However, many of the indicators related to the TBL have been criticized mainly due to their subjectivity. In addition, other issues can be pointed out regarding the set of attributes of the three dimensions; the methods used to choose the shape of functional aggregation and the weighting technique to establish the relative importance of attributes. Therefore, the construction of composite indicators for assessing agribusiness sustainability is still at an early stage, and new development is indeed needed (Gómez-Limón & Riesgo 2009).

Two major methods of aggregation of products, inputs and negative externalities in order to measure the socio-environmental behaviour efficiently can be found in the literature. The first method uses market prices as weights of inputs and outputs, and forecasts of shadow prices of externalities, due to the absence of a market for some undesirable products. Pittman (1983) was one of the pioneers in this stream of research, using parametric methods. Other studies can also be highlighted: Färe et al. (1993), Coggins and Swinton (1996), Swinton (1998) and Reig-Martínez et al. (2001). The second method uses endogenous weights estimated by non-parametric techniques, mainly using the DEA method. The weighting of each dimension varies from one production unit to another and is calculated in a more flexible way with this method. This procedure assumes that the evaluated units can combine inputs and products (desirable and undesirable) differently, finding the best adaptations taking into account their specializations, which are imperative when evaluating the environmental efficiency.

The first publication using DEA and considering desirable and undesirable outputs following asymmetric shaped can be attributed to Färe et al. (1986), which adapt hyperbolic measures of efficiency. There are also other methodological approaches to address the externalities with the DEA (Tyteca 1996). Scheel (2001) compares other forms of DEA modelling of undesirable products, as for instance considering them simply as input; multiplying undesirable outputs by -1; modelling them by a positive translation of negative values; addressing them as an inverse value to output; and using the Weakly Disposable Outputs property.

More recently, Chung et al. (1997) and Färe and Grosskopf (2000) have recommended the use of an alternative approach called Directional Distance Function (DDF) as a more flexible way to incorporate externalities in the traditional production theory and in the assessment of environmental efficiency.

Thus, the rapid evolution of DEA efficiency studies which consider externalities can be proven by the large number of published papers whose object is agribusiness. Some examples of the extensive application of DDF in agriculture are found in Färe et al. (2006), which estimated efficiency of US agriculture, shadow prices of pollutants and pollution costs associated; in Kjærsgaard et al. (2009), which assessed the Danish cod fisheries; in Azad and Ancev (2010), which analysed the economic and environmental performance of a set of irrigated farms in Australia; in Picazo-Tadeo et al. (2012), which applied the method in a sample of Spanish olive farms, among others.

Unfortunately, the use of DEA method to study the sustainability of Brazilian agribusiness is still incipient, considering the importance of this segment in the national economy (Gomes 2008).

The closest reference to the present research is the study of sustainability in Brazilian agribusiness conducted by Gomes et al. (2009), using DEA models with weight restrictions, which aimed to assess the ability of farmers in maintaining their production system over time.

The use of DEA to analyse the sustainability of other sectors of the Brazilian economy is also not extensive, but in recent years, there have been a growing number of studies, as for instance, papers from Camioto et al. (2014) and Costa et al. (2013). The first study used a DEA-SBM (slack-based model) and a window analysis to evaluate the ability of industries to reduce energy consumption and fossil-fuel CO_2 emissions, as well as to increase the gross domestic product (GDP), the number of employed persons and personnel expenses. The second study uses DEA with the restrictions on virtual weights to assess the sustainability of biodiesel production with different resources.

3. Directional distance functions and data envelopment analysis

This section presents the theoretical framework of the environmental efficiency model of the study. First, the section brings the definition of the reference technology of the segment, that is, the generic form by which an input vector (input) is combined and transformed into a vector of new goods and services (output). This process is estimated by the set of production possibilities (SPP), which incorporates all the p outputs $\left(y \in R_{+}^{p}\right)$ that can be produced with the input vector $\left(x \in R_{+}^{n}\right)$ for k observed decision-making units (DMUs). Formally, the SPP can be represented as shown in Equation (1).

$$\text{SPP} = \{(x, y) | x \text{ can produce } y; x, y \geq 0\} \quad (1)$$

In addition, the SPP shall comply with the following classical properties, as formulated in Grosskopf (1986):

- $(0,0) \in \text{SPP} \Rightarrow y(0) = 0$, which means that it is technologically possible to produce anything as well as nothing
- SPP is convex, closed and admits that only finite y can be produced by finite x
- $\forall y \in R_{+}^{p}, \forall x \in R_{+}^{n}, (x, y) \in \text{SPP}, \quad y' \leq y$ and $x' \geq x \Rightarrow (x', y)$ and $(x, y') \in \text{SPP}$. This property is called *Strong Disposability of Inputs and Outputs (SDIO)*.

The strong disposability of inputs implies that, on the one hand, it is feasible to produce the same amount of output using a larger quantity of any input x. On the other hand, strong disposability of outputs suggests that it is possible to produce a minor amount of y using the same amount of x (Grosskopf 1986).

The border of SPP is comprised by the smallest possible amount of inputs to produce a given output vector or the highest possible level of production with a particular input vector. Therefore, the efficient DMUs constitute the frontier. The inefficient DMUs stay below the frontier, and the inefficiency indexes are obtained by comparing their production units with those of the efficient DMUs. It is possible to measure the inefficiency of a DMU from the minimum distance separating that unit from the efficient frontier, which defines a measure of how the unit must change its inputs and/or outputs to become efficient (Cooper et al. 2000).

The distance function of Shephard (1954), reciprocal to Farrell's (1957) Efficiency Index ($F(x, y)$), is used to estimate efficiency. The distance function oriented to outputs can be determined as $D_o(x, y) = \text{Min}\left\{\theta : \left(x, \frac{y}{\theta}\right) \in P(x)\right\}$, where $\theta \in (0, 1]$ and measures the maximum proportional expansion of all outputs y that is feasible within given inputs x, that is, $y = P(x)$. The distance function oriented to inputs is defined as $D_i(x, y) = \text{Max}\left\{\delta : \left(\frac{x}{\delta}, y\right) \in L(y)\right\}$, in which $\delta \geq 1$ shows in what proportion the inputs can be reduced in the input space, $L(y) = \{x : y \in P(x)\}$. When $\theta = \delta = 1$, the evaluated DMU is efficient. When the $\theta < 1$ and $\delta > 1$, the DMU is inefficient. Thus, the relationship between the distance function and Farrell's Efficiency Index, calculated by the DEA method, is represented as $D_o(x, y) = [F_o(x, y)]^{-1}$ and $D_i(x, y) = [F_i(x, y)]^{-1}$.

Considering the social and environmental externalities, the new output vector $\left(u \in R_{+}^{m}\right)$ is divided into desirable and undesirable $u = (y, b)$ elements, where, respectively, y is the first subvector and $b \in R_{+}^{q}$ is the second. Thus, $\text{SPP} = \left\{(x, y, b) \in R_{+}^{n+p+q}\right\}$ and $m = p + q$, which according to Färe et al. (2006), two additional properties must be satisfied:

- $\forall y \in R_{+}^{p}, \forall b \in R_{+}^{q}, b = 0 \Rightarrow y = 0$ (null-jointness). This property indicates that production of desired outputs involves the generation of undesired outputs;
- $\forall y \in R_{+}^{p}, \forall b \in R_{+}^{q}, \quad (x, y, b) \in \text{SPP} \Rightarrow (x, \alpha y, \alpha b) \in \text{SPP}, \quad 0 \leq \alpha \leq 1$. This property, called *Weak Disposability of Outputs* (*WDO)*, suggests that the proportional reduction of both types of outputs is possible, but the elimination of separately undesirable outputs is impossible in the efficient frontier.

Therefore, in the weak disposability, the reduction of externalities is linked to a productive cost and, in this case, to three types of trade-offs imposed by the scarcity of resources: between production and pollution, between production and equality and, consequently, between pollution and equality.

The trade-off between production and pollution results from the lack of fully clean technologies and from the existence of environmental regulations, which implies that the elimination of pollutants involves compensation. This cost, measured in terms of opportunity, can be considered as the reduction in the value of the optimal production to comply with the regulation.

The trade-off between production and equality emerges because, in order to the society to obtain equality, a unit must sacrifice resources that could increase production. In contrast, if production is prioritized, society will have to sacrifice equality. The trade-off between equality and pollution stems from the other conflicts between.

The trade-offs of the model can be elucidated graphically. Figure 1 assumes that the evaluated DMUs $(\text{A}, \text{B}, \text{C}, \text{D}, \text{E and F})$, using a given amount of input (x), produce a desirable output (y) and generate an environmental or social externality (b). The area OABCDE represents the SPP^{wdo}, where efficient frontier is comprised by segments OA, AB, BC and CD. This means that the efficient frontier (OABCD) is composed of different efficient allocations on a Pareto perspective. The DMUs in the efficient frontier cannot produce one more desirable output or one less undesirable output without reducing the amount of another desirable production, given the allocation of inputs and the current technology.

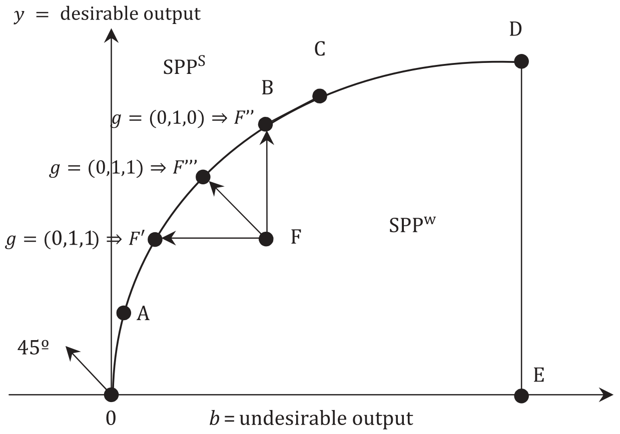

Figure 1. Trade-off between production and equality.

The most concerning issue in the analysis is the level of inefficiency of other units, particularly in a context of great need for accountability and rationality in the use of available resources and generation of undesirable sub-products. If the resources are not efficiently allocated, the DMU will be one point, as for instance F, located below the efficient frontier. Every change made to take the unit F to a point between F′ and F‴ will be a progress towards Pareto optimality, since it improves the behaviour in a dimension without worsening the situation in others.

Formally, assuming constant returns to scale and strong disposal of desirable outputs, the SPP that satisfies the property of weak disposal of undesirable outputs is $\text{SPP}^w = \{(x,y,z) \in R_+^{n+p+q} : Xz \le x, Yz \ge y, Bz = b, z \in R_+^k\}$, where the intensity vector z represents the relative weights of each DMU in the definition of the reference hyperplane, $x = (x_1, x_2, \ldots, x_n)$ is the input vector used in order to produce the vector $y = (y_1, y_2, \ldots, y_p)$ and the vector $b = (b_1, b_2, \ldots, b_q)$. Consequently, $X_{(nxk)}, Y_{(pxk)}, B_{(qxk)}$, respectively, represent the matrices of inputs, of desirable outputs and of undesirable outputs from a sample of k DMUs analysed.

The levels of environmental inefficiency of a DMU can be calculated using the method proposed by Chung et al. (1997), which introduced the concept of DDF, an extension of the distance function defined by Shephard (1954):

$$\vec{D} = (x, y, z; g_x, g_y, g_b) = \max\{\beta : (x - \beta g_x, y + \beta g_x, b - \beta g_b) \in \text{SPP}\} \quad (2)$$

The distance function estimates the optimal value of β, which must be greater than or equal to zero. This relation gives a wide range of workable indicators that represent different objectives linked to, for instance, economic, social and ecological development, according to the direction established by the vector g defined a priori by the researcher. In particular, β can indicate the percentage in which the evaluated DMU could increase all desirable products and reduce, simultaneously, the inputs and the negative externalities until the SPP frontier, when the vector g is $(g_x = 1, g_y = 1, g_b = 1)$. If $\beta = 0$, the evaluated unit is socio-environmentally efficient. For each DMU, β and z are calculated by solving the following linear programming problem (LPP).

$$\vec{D}_k^w = (x_k, y_k, b_k; -g_x, g_y, -g_b) = \text{Max } \beta \quad (3)$$

Subject to:

$$(1 + \beta g_y) \times y_k \le Yz \quad (3.1)$$

$$(1 - \beta g_b) \times b_k \le Bz \quad (3.2)$$

$$(1 - \beta g_x) \times x_k \ge Xz \quad (3.3)$$

$$z_k \ge 0 \quad (3.4)$$

Aspiring to know how much can be added to desired output of F with the same level of environmental impact and use of inputs, that is, determining $g = (g_x = 0, g_y = 1, g_b = 0)$, the LPP will make a projection of F at the point $F' = [b^F, Y^F \times (1 + \beta g_x)]$, according to Figure 1.

For each directional vector established a priori, depending on the goals that the decision-maker must pursue, the DDF allows the calculation of different measures of sustainability, which satisfy the Pareto optimality concept. This flexibility is particularly important to estimate the set of performance indicators that may simultaneously enhance the economic, ecological and social dimensions. Table 1 shows eight possible combinations of the directional vector with their different goals.

Table 1. Directional vectors and goals on economics and socio-environmental behaviour.

No.	Combinations		Goals
1	$\vec{D}_{io}^w$	(1, 1, 1)	Maximize y and minimize simultaneously x and b.
2	$\vec{D}_o^w$	(0, 1, 1)	Maximize y and minimize b with fixed vectors of x.
3	$\vec{D}_b^w$	(0, 0, 1)	Minimize b with fixed vectors of x and y.
4	–	(0, 0, 0)	Maintain the *Status quo*.
5	$\vec{D}_{iy}^w$	(1, 1, 0)	Maximize y minimize x with fixed vectors of b.
6	$\vec{D}_{oi}^w$	(1, 0, 0)	Minimize x with fixed vectors of y and b.
7	$\vec{D}_{ib}^w$	(1, 0, 1)	Minimize b and x with fixed vectors of y.
8	$\vec{D}_y^w$	(0, 1, 0)	Maximize y with fixed vectors of x and b.

4. Units and parameters of analysis

The study uses data from 33 DMUs, segregated by the 27 Brazilian states, 5 geographic regions and the overall country. The variables of the model comprise three inputs, one desirable output and two undesirable outputs. The choice of inputs and outputs is based on previous mentioned studies in Sections 1 and 2. The starting point is based on the following principle: agricultural activities of territorial units are seen as any other productive function, represented by the technical relationship between a set of productive factors or inputs that are combined to generate a given set of desired outputs. This process has negative environmental and social impacts measured, respectively, by a proxy associated with global warming and a variable that reflects the impossibility of access or lack of resources to meet basic human needs. In this study, positive externalities, such as the creation of employment and income, are not taken into account.

Based on Gomes (2008), the inputs of the model are:

- x_1 – employed persons divided by the total area (km^2) of enterprises;
- x_2 – agricultural inputs (fertilizers, seeds and seedlings, packaging, pesticides, medicines and animal feed, electricity, fuels, raw materials, among others). In all cases, US$ 416 was adopted per total area of enterprises (km^2); and
- x_3 – estimated capital by depreciation of fixed capital assets (machinery, implements, buildings, facilities, among others). In all cases, US$ 416 was adopted per total area of enterprises (km^2).

Considering the three dimensions of sustainability, the outputs selected were:

- y (desirable output) – Value of total production at US$ 416 per total area of enterprises
- b_1 (social undesirable output) – Thousands of poor people in rural area, in 2006
- b_2 (environmental undesirable output) – Values of emissions of GHG, in 2006 in CO_2 tons-equivalent, divided by the total area of enterprises

The first four variables were obtained from the Brazilian Agricultural Census (2006), published by the Brazilian Institute of Geography and Statistics (IBGE 2006). The source of the fifth variable b_1 is the Institute for Work and Society of Brazil, which estimates the number of poor people and the poverty line based on the National Household Sample Survey of Brazil. This limit, according to the place of residence, includes the value of the food basket and the minimum amount to meet all the other basic needs: housing, clothing, hygiene, health, education, transport, leisure, among others.

The sixth variable b_2 was estimated based on four reports of GHG emissions from the agricultural segment, developed by the Brazilian Agricultural Research Corporation (Embrapa) considering the following elements:

- Methane emissions from enteric fermentation and manure of livestock management (Lima, Pessoa, et al. 2010)
- Methane emissions from rice cultivation (Lima, Ligo, Pessoa, Luiz, et al. 2010)
- GHG emissions from the burning of agricultural waste (Lima, Ligo, Pessoa, Neves, et al. 2010)
- Nitrous oxide emissions from agricultural soils and manure (Alves 2010)

It is important to emphasize that these reports calculate GHG emissions by Brazilian regions and states in 2006, except for the emission of nitrous oxide (N_2O) from agricultural soils and manure management. This latest report only gives (N_2O) emissions from 1990 to 2006 in Brazil. Therefore, considering the rate of growth of these emissions in the last 10 years in Brazil and, records by Brazilian states in 1995, values of (N_2O) for 2006 were estimated. With each GHG emissions were also calculated tons of equivalent CO_2 based on metric of Global Temperature Potential (GTP).

Table 2 shows the units (Brazilian States) contemplated, the data and the descriptive statistics of the selected variables. Note that Mato Grosso and Amapá have the lowest levels in inputs per km^2, Distrito Federal has the highest level of production, Amapá, the fewest number of poor people and Mato Grosso, the lower GHG emissions.

5. Results

Considering the parameters described in the previous section, the optimal set of indicators was estimated, representing the different goals in relation to economic, social and environmental performance, following the order of Table 1. In Table 3, the values of $\vec{D}^w_{io}(1,1,1,1,1,1)$ show a high level of environmental inefficiency, with an average of 0.155. In addition, these values suggest how much desirable production can increase simultaneously, reducing inputs and negative externalities. Taking into account global values of the segment, the increment of desirable production may be 5.9%, the reduction of employed persons 10.4%, the reduction of agro inputs 6.6% and the reduction in capital 7.8%. The poverty alleviation and GHG emissions can be reduced, respectively, to 15.6% and 4.1%, as shown in Table 3. These results show that, in the period under review, if inefficient Brazilian states had adopted the best practices, it would make possible to foster an agriculture that potentiates the economic, ecological, and social dimensions. Therefore, the apparent antagonism among these three attributes does not prevent the formulation of policies that could be consistent with maximization of social welfare.

In the first part of Table 4, the indicator $\vec{D}^w_{yb}$, defining the percentage in which the Brazilian states could increase the desirable output and, simultaneously, reduce the

Table 2. Units, data and descriptive statistics of selected variables (2006).

No.	DMUs	x_1 - People.	x_2 - Input.	x_3 - Capital.	y - Production.	b_2 - No. poor people.	b_2 - GHG
1	Rondônia	3335	7831	3864	10,214	73,964	0.071
2	Acre	2852	3121	2886	9964	61,902	0.031
3	Amazonas	7337	3973	1284	17,899	220,406	0.023
4	Roraima	1736	2.989	1187	5819	10,834	0.024
5	Pará	3526	5087	1797	14,847	313,491	0.048
6	Amapá	1499	0.385	0.549	11,470	4866	0.025
7	Tocantins	1237	7372	2271	5352	63,897	0.039
8	Maranhão	7633	7245	1526	24,027	978,882	0.037
9	Piauí	8750	6254	2010	13,968	573,779	0.035
10	Ceará	14,465	10,535	3471	48,575	807,135	0.041
11	Rio Grande do Norte	7764	6435	3795	35,164	234,974	0.033
12	Paraíba	12,961	13,699	4068	37,592	276,660	0.038
13	Pernambuco	17,389	34,700	4434	88,685	804,538	0.055
14	Alagoas	21,426	46,460	5787	155,247	492,473	0.077
15	Sergipe	18,157	58,566	4866	71,954	132,752	0.063
16	Bahia	7971	18,735	2474	28,838	1,623,194	0.042
17	Mato Grosso do Sul	0.703	12,961	3592	11,855	74,283	0.070
18	Mato Grosso	0.750	22,577	3316	20,085	150,180	0.020
19	Goiás	1628	20,363	4950	24,304	107,878	0.028
20	Distrito Federal	8883	85,391	34,947	172,222	26,448*	5.502
21	Minas Gerais	5810	35,085	6731	57,705	447,522	0.050
22	Espírito Santo	11,189	32,192	12,024	82,563	96,620	0.148
23	Rio de Janeiro	7695	22,640	10,170	60,903	529,212	0.845
24	São Paulo	5453	81,020	14,419	152,821	181,737	0.229
25	Paraná	7308	55,061	5506	103,999	180,471	0.085
26	Santa Catarina	9462	58,259	22,835	146,911	49,796	0.204
27	Rio Grande do Sul	6098	46,899	15,074	82,644	217,451	0.024
	Sum	203,016	705,838	179,834	1,495,629		7.887
	Average	7519	26,142	6661	55,394		0.292
	Maximum	21,426	85,391	34,947	172,222	1,623,194	5.502
	Minimum	0.703	0.385	0.549	5352	4866	0.020
28	North	3022	5761	2231	11,223	749,360	0.045
29	Northeast	10,184	16,262	2773	37,587	5,924,387	0.042
30	Midwest	0.973	19,397	3876	19,114	332,341	0.050
31	Southeast	6053	48,609	9505	88,417	791,744	0.080
32	South	7033	51,556	12,681	99,853	447,718	0.053
33	Brazil	5021	25,264	5384	43,590	8,245,550	0.059

Note: In the Distrito Federal, only the number of poor people is given. Its rural value was estimated considering the non-urban population percentage (3.38%).

Table 3. Indicator of socio-environmental efficiency $\vec{D}_{io}^{w}(1,1,1,1,1,1)$ and the goals of improvement for each analysed units.

DMUs	$\vec{D}_{io}^{w}$	$(1-\beta)\times x_1$	$(1-\beta)\times x_2$	$(1-\beta)\times x_3$	$(1-\beta)\times b_1$	$(1-\beta)\times b_2$	$(1-\beta)\times y$
Rondônia	0.549	1.504085	3.531781	1.742664	33,357.764	0.032021	15.821486
Acre	0.359	1.828132	2.000561	1.849926	39,679.182	0.019871	13.541076
Amazonas	0.082	6.735366	3.647214	1.178712	202,332.71	0.021114	19.366718
Roraima	0.424	0.999936	1.721664	0.683712	6240.384	0.013824	8.286256
Pará	0.324	2.383576	3.438812	1.214772	211,919.92	0.032448	19.657428
Amapá	0.000	1.499	0.385	0.549	4866	0.025	11.47
Tocantins	0.563	0.540569	3.221564	0.992427	27,922.989	0.017043	8.365176
Maranhão	0.130	6.64071	6.30315	1.32762	851,627.34	0.03219	27.15051
Piauí	0.390	5.3375	3.81494	1.2261	350,005.19	0.02135	19.41552
Ceará	0.000	14.465	10.535	3.471	807,135	0.041	48.575
Rio Grande do Norte	0.000	7.764	6.435	3.795	234,974	0.033	35.164
Paraíba	0.189	10.511371	11.109889	3.299148	224,371.26	0.030818	44.696888
Pernambuco	0.098	15.684878	31.2994	3.999468	725,693.28	0.04961	97.37613
Alagoas	0.000	21.426	46.46	5.787	492,473	0.077	155.247
Sergipe	0.035	17.521505	56.51619	4.69569	128,105.68	0.060795	74.47239
Bahia	0.292	5.643468	13.26438	1.751592	1,149,221.4	0.029736	37.258696
Mato Grosso do Sul	0.220	0.54834	10.10958	2.80176	57,940.74	0.0546	14.4631

(*Continued*)

Table 3. (Continued).

DMUs	$\vec{D}^{w}_{io}$	$(1-\beta)\times x_1$	$(1-\beta)\times x_2$	$(1-\beta)\times x_3$	$(1-\beta)\times b_1$	$(1-\beta)\times b_2$	$(1-\beta)\times y$
Mato Grosso	0.000	0.75	22.577	3.316	150,180	0.02	20.085
Goiás	0.124	1.426128	17.837988	4.3362	94,501.128	0.024528	27.317696
Distrito Federal	0.000	8.883	85.391	34.947	19,374.254	5.502	172.222
Minas Gerais	0.115	5.14185	31.050225	5.956935	396,056.97	0.04425	64.341075
Espírito Santo	0.129	9.745619	28.039232	10.472904	84,156.02	0.128908	93.213627
Rio de Janeiro	0.162	6.44841	18.97232	8.52246	443,479.66	0.70811	70.769286
São Paulo	0.000	5.453	81.02	14.419	181,737	0.229	152.821
Paraná	0.000	7.308	55.061	5.506	180,471	0.085	103.999
Santa Catarina	0.000	9.462	58.259	22.835	49,796	0.204	146.911
Rio Grande do Sul	0.000	6.098	46.899	15.074	217,451	0.024	82.644
Average	0.155						
Sum		181.74944	658.90089	165.75109	7,365,068.8	7.561216	1584.6511
Δ%		–10.476	–6.649	–7.831	–15.618	–4.131	5.952
North	0.403	1.804134	3.439317	1.331907	447,367.92	0.026865	15.745869
Northeast	0.000	10.184	16.262	2.773	5,924,387	0.042	37.587
Midwest	0.107	0.868889	17.321521	3.461268	296,780.51	0.04465	21.159198
Southeast	0.029	5.877463	47.199339	9.229355	768,783.42	0.07768	90.981093
South	0.000	7.033	51.556	12.681	447,718	0.053	99.853
Brazil	0.000	5.021	25.264	5.384	8,245,550	0.059	43.59

Table 4. Indicator of socio-environmental efficiency $\vec{D}^{w}_{yb}(0,0,0,1,1,1)$ and $\vec{D}^{w}_{b}(0,0,0,0,1,1)$ and goals of improvement of each analysed units.

DMUs	$\vec{D}^{w}_{yb}$	$(1-\beta)\times b_1$	$(1-\beta)\times b_2$	$(1-\beta)\times y$	$\vec{D}^{w}_{b}$	$(1-\beta)\times b_1$	$(1-\beta)\times b_2$
Rondônia	0.74	19,378.568	0.018602	17.751932	0.85	11,020.636	0.010579
Acre	0.48	32,065.236	0.016058	14.766648	0.69	19,065.816	0.009548
Amazonas	0.12	194,398.09	0.020286	20.011082	0.35	143,263.9	0.01495
Roraima	0.50	5471.17	0.01212	8.699405	0.69	3347.706	0.007416
Pará	0.54	143,578.88	0.021984	22.894074	0.86	45,456.195	0.00696
Amapá	0.00	4866	0.025	11.47	0.00	4866	0.025
Tocantins	0.79	13,610.061	0.008307	9.564024	0.88	7603.743	0.004641
Maranhão	0.22	761,570.2	0.028786	29.360994	0.63	361,207.46	0.013653
Piauí	0.61	223,773.81	0.01365	22.48848	0.84	91,230.861	0.005565
Ceará	0.00	807,135	0.041	48.575	0.00	807,135	0.041
Rio Grande do Norte	0.00	234,974	0.033	35.164	0.00	234,974	0.033
Paraíba	0.29	196,981.92	0.027056	48.418496	0.56	122,283.72	0.016796
Pernambuco	0.10	720,866.05	0.04928	97.90824	0.20	643,630.4	0.044
Alagoas	0.00	492,473	0.077	155.247	0.00	492,473	0.077
Sergipe	0.04	127,972.93	0.060732	74.544344	0.07	123,459.36	0.05859
Bahia	0.46	881,394.34	0.022806	42.016966	0.66	555,132.35	0.014364
Mato Grosso do Sul	0.61	29,118.936	0.02744	19.06284	0.81	14,113.77	0.0133
Mato Grosso	0.00	150,180	0.02	20.085	0.00	150,180	0.02
Goiás	0.19	86,949.668	0.022568	29.018976	0.50	53,723.244	0.013944
Distrito Federal	0.00	19,374.254	5.502	172.222	0.00	19,374.254	5.502
Minas Gerais	0.20	35,8017.6	0.04	69.246	0.54	206,307.64	0.02305
Espírito Santo	0.15	81,837.14	0.125356	95.195139	0.32	66,184.7	0.10138
Rio de Janeiro	0.41	310,647.44	0.496015	86.055939	0.91	48,158.292	0.076895
São Paulo	0.00	181,737	0.229	152.821	0.00	181,737	0.229
Paraná	0.00	180,471	0.085	103.999	0.00	180,471	0.085
Santa Catarina	0.00	49,796	0.204	146.911	0.00	49,796	0.204
Rio Grande do Sul	0.00	217,451	0.024	82.644	0.00	217,451	0.024
Average	0.24				0.38		
Sum		6526,089.3	7.251046	1636.1416		4,853,647	6.675631
Δ%		–25.230	–8.063	9.395		–44.392	–15.359
North	0.75	184,342.56	0.01107	19.685142	0.91	64,444.96	0.00387
Northeast	0.00	5,924,387	0.042	37.587	0.00	5,924,387	0.042
Midwest	0.32	226,656.56	0.0341	25.192252	0.71	98,040.595	0.01475
Southeast	0.05	750,573.31	0.07584	93.014684	0.26	589,849.28	0.0596
South	0.00	447,718	0.053	99.853	0.00	447,718	0.053
Brazil	0.00	8,245,550	0.059	43.59	0.00	8,245,550	0.059

negative externalities with the same level of inputs, has an average value of 0.24. This result shows that an effective strategy with economic, social and environmental responsibility could increase production of the agribusiness sector by 9.4% and decrease the percentage of poor people and the emissions of GHG by, respectively, 25.2% and 8.1%. This potential is feasible in the 17 Brazilian states, where there is $\vec{D}^{w}_{yb} > 0$.

In the second part of Table 4, the indicator $\vec{D}^{w}_{b}$, related to the rate at which the Brazilian states could reduce the negative externalities with the same level of input and production, has an average value of 0.38. This result suggests an estimated reduction in poverty and emissions of GHG by, respectively, 44.4% and 15.3%. This evidence from the study, of prominent importance to sustainability, can serve as a reference in the definition of goals to the Brazilian federal governmental as well as of commitments to international standards regarding reduces in GHG emissions in the country.

Results indicate that another interesting strategy may emerge if producers direct efforts to increase productivity, i.e., the ratio products/inputs, without changing the negative externalities. This strategy can be designed with the assistance of the indicator $\vec{D}^{w}_{iy}$, which has an average value of 0.17, as shown in Table 5. Thus, with the same level of environmental and social impact, the segment can increase the desired output by 6.8% and reduce, in parallel, the three inputs, employed personnel, agricultural inputs and capital, by, respectively, 12%, 7.5% and 8.6 %.

In Table 5, from the second indicator, the most interesting unit must be the largest producer. The indicator $\vec{D}^{w}_{i}$ shows the capability of reducing human resource and property costs by 0.26 on average, without affecting the level of production and the environmental impact. Whether the 17 inefficient Brazilian states adopt best practices, the reduction in human resources would be 20.2%, in input factors would be 13.3%, and in capital would be 14.1%.

The indicator $\vec{D}^{w}_{ib}$ can be obtained from the directional vector, which seeks to minimize externalities and agricultural inputs with a fixed vector of a desired product. The average value of this indicator is 0.23, as shown in

Table 5. Indicator of socio-environmental efficiency $\vec{D}^{w}_{iy}(1,1,1,1,0,0)$ and $\vec{D}^{w}_{i}(1,1,1,0,0,0)$ and goals of improvement of each analysed units.

DMUs	$\vec{D}^{w}_{iy}$	$(1-\beta)\times x_1$	$(1-\beta)\times x_2$	$(1-\beta)\times x_3$	$(1-\beta)\times y$	$\vec{D}^{w}_{i}$	$(1-\beta)\times x_1$	$(1-\beta)\times x_2$	$(1-\beta)\times x_3$
Rondônia	0.54	1.521	3.571	1.762	15.770	0.70	1.001	2.349	1.159
Acre	0.43	1.634	1.788	1.654	14.219	0.60	1.155	1.264	1.169
Amazonas	0.10	6.603	3.576	1.156	19.689	0.23	5.679	3.075	0.994
Roraima	0.49	0.894	1.539	0.611	8.641	0.65	0.606	1.043	0.414
Pará	0.34	2.320	3.347	1.182	19.925	0.48	1.819	2.625	0.927
Amapá	0.00	1.499	0.385	0.549	11.470	0.00	1.499	0.385	0.549
Tocantins	0.56	0.549	3.273	1.008	8.328	0.71	0.360	2.145	0.661
Maranhão	0.12	6.717	6.376	1.343	26.910	0.19	6.206	5.890	1.241
Piauí	0.48	4.533	3.240	1.041	20.701	0.60	3.491	2.495	0.802
Ceará	0.00	14.465	10.535	3.471	48.575	0.00	14.465	10.535	3.471
Rio Grande do Norte	0.00	7.764	6.435	3.795	35.164	0.00	7.764	6.435	3.795
Paraíba	0.23	9.967	10.535	3.128	46.276	0.44	7.258	7.671	2.278
Pernambuco	0.13	15.163	30.258	3.866	100.037	0.22	13.633	27.205	3.476
Alagoas	0.00	21.426	46.460	5.787	155.247	0.00	21.426	46.460	5.787
Sergipe	0.07	16.886	54.466	4.525	76.991	0.26	13.491	43.515	3.615
Bahia	0.25	5.970	14.033	1.853	36.076	0.36	5.093	11.972	1.581
Mato Grosso do Sul	0.21	0.557	10.278	2.848	14.309	0.33	0.473	8.723	2.417
Mato Grosso	0.00	0.750	22.577	3.316	20.085	0.00	0.750	22.577	3.316
Goiás	0.15	1.390	17.390	4.227	27.852	0.31	1.131	14.152	3.440
Distrito Federal	0.00	8.883	85.391	34.947	172.222	0.00	8.883	85.391	34.947
Minas Gerais	0.12	5.101	30.805	5.910	64.745	0.23	4.474	27.015	5.183
Espírito Santo	0.18	9.197	26.462	9.884	97.259	0.34	7.362	21.182	7.912
Rio de Janeiro	0.16	6.479	19.063	8.563	70.526	0.27	5.640	16.595	7.455
São Paulo	0.00	5.453	81.020	14.419	152.821	0.00	5.453	81.020	14.419
Paraná	0.00	7.308	55.061	5.506	103.999	0.00	7.308	55.061	5.506
Santa Catarina	0.00	9.462	58.259	22.835	146.911	0.00	9.462	58.259	22.835
Rio Grande do Sul	0.00	6.098	46.899	15.074	82.644	0.00	6.098	46.899	15.074
Average	0.17					0.26			
Sum		178.591	653.021	164.262	1597.391		161.981	611.940	154.423
Δ%		–12.031	–7.482	–8.659	6.804		–20.213	–13.303	–14.130
North	0.39	1.831	3.491	1.352	15.645	0.51	1.496	2.852	1.104
Northeast	0.00	10.184	16.262	2.773	37.587	0.00	10.184	16.262	2.773
Midwest	0.10	0.880	17.535	3.504	20.949	0.16	0.817	16.293	3.256
Southeast	0.03	5.865	47.102	9.210	91.158	0.06	5.666	45.498	8.897
South	0.00	7.033	51.556	12.681	99.853	0.00	7.033	51.556	12.681
Brazil	0.00	5.021	25.264	5.384	43.590	0.00	5.021	25.264	5.384

Table 6. Indicator of socio-environmental efficiency $\vec{D}^w_{ib}(1,1,1,0,1,0)$ and $\vec{D}^w_i(0,0,0,1,0,0)$ and goals of improvement of each analysed units.

DMUs	$\vec{D}^w_{ib}$	$(1-\beta)\times x_1$	$(1-\beta)\times x_2$	$(1-\beta)\times x_3$	$(1-\beta)\times b_1$	$(1-\beta)\times b_2$	$\vec{D}^w_y$	$(1-\beta)\times y$
Rondônia	0.71	0.970485	2.278821	1.124424	21,523.524	0.020661	2.43	35.074876
Acre	0.53	1.346144	1.473112	1.362192	29,217.744	0.014632	1.12	21.113716
Amazonas	0.15	6.229113	3.373077	1.090116	187,124.69	0.019527	0.18	21.085022
Roraima	0.60	0.70308	1.210545	0.480735	4387.77	0.00972	1.47	14.378749
Pará	0.49	1.79826	2.59437	0.91647	159,880.41	0.02448	0.96	29.10012
Amapá	0.00	1.499	0.385	0.549	4866	0.025	0.00	11.47
Tocantins	0.72	0.34636	2.06416	0.63588	17,891.16	0.01092	2.58	19.138752
Maranhão	0.23	5.87741	5.57865	1.17502	753,739.14	0.02849	0.30	31.211073
Piauí	0.56	3.84125	2.745506	0.88239	251,888.98	0.015365	1.28	31.833072
Ceará	0.00	14.465	10.535	3.471	807,135	0.041	0.00	48.575
Rio Grande do Norte	0.00	7.764	6.435	3.795	234,974	0.033	0.00	35.164
Paraíba	0.32	8.839402	9.342718	2.774376	188,682.12	0.025916	0.47	55.109872
Pernambuco	0.18	14.276369	28.4887	3.640314	660,525.7	0.045155	0.22	108.01833
Alagoas	0.00	21.426	46.46	5.787	492,473	0.077	0.00	155.247
Sergipe	0.07	16.922324	54.583512	4.535112	123,724.86	0.058716	0.07	77.206642
Bahia	0.45	4.368108	10.26678	1.355752	889,510.31	0.023016	0.83	52.658188
Mato Grosso do Sul	0.36	0.449217	8.282079	2.295288	47,466.837	0.04473	0.57	18.553075
Mato Grosso	0.00	0.75	22.577	3.316	150,180	0.02	0.00	20.085
Goiás	0.22	1.26984	15.88314	3.861	84,144.84	0.02184	0.28	31.157728
Distrito Federal	0.00	8.883	85.391	34.947	19,374.254	5.502	0.00	172.222
Minas Gerais	0.21	4.60733	27.822405	5.337683	354,884.95	0.03965	0.26	72.7083
Espírito Santo	0.23	8.637908	24.852224	9.282528	74,590.64	0.114256	0.30	106.91909
Rio de Janeiro	0.28	5.548095	16.32344	7.33257	381,561.85	0.609245	0.39	84.472461
São Paulo	0.00	5.453	81.02	14.419	181,737	0.229	0.00	152.821
Paraná	0.00	7.308	55.061	5.506	180,471	0.085	0.00	103.999
Santa Catarina	0.00	9.462	58.259	22.835	49,796	0.204	0.00	146.911
Rio Grande do Sul	0.00	6.098	46.899	15.074	217,451	0.024	0.00	82.644
Average	0.23						0.51	
Sum		169.1387	630.18524	157.78085	6,569,202.8	7.366319		1738.8771
Δ%		−16.687	−10.718	−12.263	−24.736	−6.602		16.264
North	0.57	1.287372	2.454186	0.950406	319,227.36	0.01917	1.35	26.351604
Northeast	0.00	10.184	16.262	2.773	5,924,387	0.042	0.00	37.587
Midwest	0.19	0.785211	15.653379	3.127932	268,199.19	0.04035	0.24	23.682246
Southeast	0.06	5.714032	45.886896	8.97272	747,406.34	0.07552	0.06	93.633603
South	0.00	7.033	51.556	12.681	447,718	0.053	0.00	99.853
Brazil	0.00	5.021	25.264	5.384	8,245,550	0.059	0.00	43.59

Table 6. The reduction in externalities and input factors also increases environmentally responsible productivity. In Table 6, indicator $\vec{D}^w_{ib}$ shows that poverty and GHG can be mitigated by, respectively, 24.7% and 6.6%; whereas employed staff can be reduced by 16.6%; capital resources by 12.2%, and agricultural inputs by 10.7%.

Finally, results of the study can be used to estimate to know how much production can be increased by keeping the other variables constant. The indicator $\vec{D}^w_y$ shown in Table 6 has an average value of 0.51 and suggests that an efficient management could increase production by 16.2%.

Summarizing the analysis of the results, the study shows a high level of relative inefficiency of Brazilian agribusiness. The federal states of Tocantins, Rondônia and Roraima are the worst performers. In addition, only 10 Brazilian states, highlighted in Table 6, achieved the best performance in all environmental efficiency indicators: São Paulo, Santa Catarina, Paraná, Rio Grande do Sul, Distrito Federal, Mato Grosso, Rio Grande do Norte, Alagoas, Ceará, and Amapá. It should be emphasized that many of these states stand out in at least one of the selected variables, as seen in the previous section and others are linear combinations of those notable states, establishing the efficient frontier. This result reveals that some efficient units tend to be more responsible than others in terms of social and environmental dimensions.

Additionally, some explanations for this high level of social and environmental inefficiency can be suggested: (1) High technical inefficiency, since the DEA-CCR oriented to output model, without considering the environmental and social impacts, estimated an average of 1.78. In this case, only four states (Amapá, Alagoas, São Paulo and Paraná) are efficient. This result implies that the Brazilian agricultural production could increase 78% if states adopt best practices; (2) The very poor social indicators in Brazil: high poverty, low education, high concentration of income and land; (3) The large regional inequality; (4) Little recognition, by the population, of environment as a public good; (5) Failure and ineffectiveness of state to enforce environmental standards and public policies of agricultural assistance, especially to the small producer.

Despite these potential explanations, analysis of the causes of low social and environmental inefficiency behaviour is beyond the scope of this study.

6. Concluding remarks

From a sustainable development perspective, the social and environmental impacts of the modernization of Brazilian agribusiness have generated a growing concern in the search for balance between socioeconomics development and the appropriate use of natural resources. In this context, this research contributes to the discussion of sustainable development in the agribusiness sector of one of the largest food producer in the world. Because of the important role Brazil plays as an importer and exporter of agricultural products, changes in efficiency in the country's productive process may have a significant impact on agricultural commodity prices all over the world.

By applying DDF and DEA methods, the study evaluated the environmental efficiency of different states in Brazil. It is important to highlight that one of the main motivations of this research was the lack of references in the literature using these combined methods focused on the Brazilian agribusiness. The study of Brazilian states can shed light to identify sources of inefficiencies, indicating the need for further research. Since the study showed large variability in the efficiency levels of the states, it would be interesting to confront performance with specific characteristics of the DMUs. For instance, climate, soil, instruction level of population, GDP per capita, educational constraints and human development index of the states could be used to explain agribusiness efficiency. In this context, the study presents some limitations as, for instance, the focus on DMUs of a single country and the small number of variables used in the model. Nevertheless, there are arguments that may weaken these limitations: the leading position of Brazil in the agribusiness and the limited number of available environmental and social data. It should also be emphasized that the choice of variables followed, for instance, Gomes and Lins (2008) and Gomes et al. (2009).

As for the results, the research estimated a set of environmental performance indicators, which, by satisfying the Pareto optimality concept, could simultaneously enhance economic, ecological and social dimensions. These indicators confirm, in different ways, the initial hypothesis that it is possible to establish consistent productive strategies that are compatible with the maximization of social welfare, despite the apparent antagonism among these three dimensions.

In addition, this study shows that efficient Brazilian states tend to combine the three dimensions in different ways. Hence, several optimal points can be obtained from different actions to reduce poverty and environmental impact without necessarily generating productive inefficiencies. This result can be considered of prominent importance for sustainable development in Brazil and can also serve as a reference in the definition of goals for the Brazilian government in an internal context as well as in the choice of international GHG emission standards to which the country could commit itself. Reducing inefficiencies in 17 states would probably enhance productivity of the agribusiness in Brazil and at the same time promote a sustainable social and environmental development.

Finally, it is worth noting that there is a great potential for research regarding the use of DDF in a DEA framework, mainly in the agribusiness sector, where an increase in productivity can occur at the expense of jeopardizing enhancements in other dimensions. Further studies can take advantage of this tool to estimate the shadow prices of pollution reduction and rural poverty. Also, studies that could explore the availability of time series data would allow the definition of dynamic models, which shifts the central issue of environmental efficiency to other very important problems such as the evolution of indicators through the years and the nature of their trajectories in the long term. Panel data would therefore make possible the study of state or country-level variables that, through time, could explain the impact not only in agribusiness production, but also in the environment and social welfare.

References

Alcantara Filho JL, Fontes RMO. 2009. A formação da propriedade e a concentração de terras no Brasil. R. Heera. 4:63–85.

Ali ASM. 2013. Targeting the poorest in developing countries: components of multidimensional deprivation in Luxor, Egypt. Int J Sustain Dev World Ecol. 20:504–511. doi:10.1080/13504509.2013.842946

Alves BJR. 2010. Emissões de óxido nitroso de solos agrícolas e de manejo de dejetos [Internet]. Relatório de Referência. Brasília: Empresa Brasileira de Pesquisa Agropecuária – Embrapa. [cited 2014 Mar 25]. Available from: http://www.cetesb.sp.gov.br/userfiles/file/mudancasclimaticas/geesp/file/docs/publicacao/nacional/2_comunicacao_nacional/rr/agricultura/brasil_mcti_solos_agricolas.pdf

Azad MAS, Ancev T. 2010. Using ecological indices to measure economic and environmental performance of irrigated agriculture. Ecol Econ. 69:1731–1739. doi:10.1016/j.ecolecon.2010.04.003

Bauler T. 2012. An analytical framework to discuss the usability of (environmental) indicators for policy. Ecol Indicators. 17:38–45. doi:10.1016/j.ecolind.2011.05.013

Bockstaller C, Girardin P. 2003. How to validate environmental indicators. Agri Sys. 76:639–653. doi:10.1016/S0308-521X(02)00053-7

Böhringer C, Jochem PEP. 2007. Measuring the immeasurable – a survey of sustainability indices. Ecol Econ. 63:1–8. doi:10.1016/j.ecolecon.2007.03.008

Bojacá CR, García SJ, Schrevens E. 2012. Investigating the technical sustainability of farming systems with correlational biplots. Int J Sustain Dev World Ecol. 19:361–368. doi:10.1080/13504509.2012.671194

Calker KJV, Berentsen PBM, Romero C, Giesen GWJ, Huirne RBM. 2006. Development and application of a multi-attribute sustainability function for Dutch dairy farming systems. Ecol Econ. 57:640–658. doi:10.1016/j.ecolecon.2005.05.016

Camioto FDC, Mariano EB, Rebelatto DADN. 2014. Efficiency in Brazil's industrial sectors in terms of energy and sustainable development. Env Sci Pol. 37:50–60. doi:10.1016/j.envsci.2013.08.007

Chung YH, Färe R, Grosskopf S. 1997. Productivity and undesirable outputs: a directional distance function approach. J Environ Manage. 51:229–240. doi:10.1006/jema.1997.0146
Claver E, López MD, Molina JF, Tarí JJ. 2007. Environmental management and firm performance: a case study. J Environ Manage. 84:606–619. doi:10.1016/j.jenvman.2006.09.012
Coggins JS, Swinton JR. 1996. The price of pollution: a dual approach to valuing SO2 allowances. J Environ Econ Manage. 30:58–72. doi:10.1006/jeem.1996.0005
Cooper WW, Seiford LM, Tone K. 2000. Data envelopment analysis: a comprehensive text with models, applications, references and Dea-Solver software. Boston (MA): Kluwer Academic Publisher.
Costa AO, Oliveira LB, Lins MPE, Silva ACM, Araujo MSM, Pereira Jr. AO Jr, Rosa LP. 2013. Sustainability analysis of biodiesel production: a review on different resources in Brazil. Renew Sust Energ Rev. 27:407–412. doi:10.1016/j.rser.2013.06.005
Cosyns H, Damme PV, Wulf RD. 2013. Who views what? Impact assessment through the eyes of farmers, development organization staff and researchers. Int J Sust Dev World Ecol. 20:287–301. doi:10.1080/13504509.2013.806372
Elkington J. 1998. Cannibals with forks – the triple bottom line of 21st century business. Gabriola Island: New Society Publishers.
Food and Agriculture Organization. 2006. Livestock's long shadow environmental issues and options. Rome: Food and Agriculture Organization of the United Nations. 978-92-5-105571-7.
Food and Agriculture Organization. 2013. World food and agriculture. Rome: Food and Agriculture Organization of the United Nations. 978-92-5-107396-4.
Färe R, Grosskopf S. 2000. Theory and application of directional distance functions. J. Prod Anal. 13:93–103. doi:10.1023/A:1007844628920
Fare R, Grosskopf S, Lovell CAK, Yaisawarng S. 1993. Derivation of shadow prices for undesirable outputs: a distance function approach. Rev Econ Statist. 75:374–380. doi:10.2307/2109448
Färe R, Grosskopf S, Pasurka C. 1986. Effects on relative efficiency in electric power generation due to environmental controls. Res. Energ. 8:167–184. doi:10.1016/0165-0572(86)90016-2
Färe R, Grosskopf S, Weber WL. 2006. Shadow prices and pollution costs in U.S. agriculture. Ecol Econ. 56:89–103. doi:10.1016/j.ecolecon.2004.12.022
Farrell MJ. 1957. The measurement of productive efficiency. J. R Stat Soc Ser A (General). 120:253–290. doi:10.2307/2343100
Fredericks SE. 2012. Justice in sustainability indicators and indexes. Int J Sust Dev World Ecol. 19:490–499. doi:10.1080/13504509.2012.714807
Gomes EG. 2008. Uso de modelos DEA em agricultura: revisão da literatura. Engevista. 10:27–51.
Gomes EG, Lins MPE. 2008. Modelling undesirable outputs with zero sum gains data envelopment analysis models. J Oper Res Soc. 59:616–623. doi:10.1057/palgrave.jors.2602384
Gomes EG, Mello JCCBSd, Souza GdSeS, Meza LA, Mangabeira JAdC 2009. Efficiency and sustainability assessment for a group of farmers in the Brazilian Amazon. In: Annals of Operations Research.
Gómez-Limón JA, Riesgo L. 2009. Alternative approaches to the construction of a composite indicator of agricultural sustainability: an application to irrigated agriculture in the Duero basin in Spain. J Environ Manage. 90:3345–3362. doi:10.1016/j.jenvman.2009.05.023
González-Benito J, González-Benito Ó. 2008. Operations management practices linked to the adoption of ISO 14001: an empirical analysis of Spanish manufacturers. Int J Prod Econ. 113:60–73. doi:10.1016/j.ijpe.2007.02.051
Govindan K, Khodaverdi R, Jafarian A. 2013. A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. J Clean Prod. 47:345–354. doi:10.1016/j.jclepro.2012.04.014
Grossi MD. 2011. A questão agrária, a agricultura familiar e a probleza no Brasil [Internet]. In: Miranda C, Tiburcio B, editors. Pobreza Rural: concepções, determinantes e proposições para a construção de uma agenda de políticas públicas; Brasília; p. 79–82. [cited 2013 Oct 27]. Available from: http://www.iicaforumdrs.org.br/iica2010/adm/adm/imagens/arquivos/Edicao%20Especial_Serie%20DRS_baixa%20resolucao.pdf.
Grosskopf S. 1986. The role of the reference technology in measuring productive efficiency. Econ J. 96:499–513. doi:10.2307/2233129
Hansmann R, Mieg HA, Frischknecht P. 2012. Principal sustainability components: empirical analysis of synergies between the three pillars of sustainability. Int J Sust Dev World Ecol. 19:451–459. doi:10.1080/13504509.2012.696220
Heyder M, Theuvsen L. 2012. Determinants and effects of corporate social responsibility in German agribusiness: a PLS model. Agribusiness. 28:400–420. doi:10.1002/agr.21305
Hoffmann R, Ney MG. 2010. Estrutura fundiária e propriedade agrícola no Brasil, grandes regiões e unidades da federação. Brasília: Ministério do Desenvolvimento Agrário.
IBGE. 2006. Censo Agropecuário [Internet]. Rio de Janeiro: Instituto Brasileiro de Geografia e Estatística – IBGE. [cited 2014 Mar 25]. Available from: ftp://ftp.ibge.gov.br/Censos/Censo_Agropecuario_2006/Segunda_Apuracao/censoagro2006_2aapuracao.pdf.
Jabbour CJC, Silva EMd, Paiva EL, Santos FCA. 2012. Environmental management in Brazil: is it a completely competitive priority? J Clean Prod. 21:11–22. doi:10.1016/j.jclepro.2011.09.003
Kjærsgaard J, Vestergaard N, Kerstens K. 2009. Ecological benchmarking to explore alternative fishing schemes to protect endangered species by substitution: the Danish Demersal Fishery in the North Sea. Environ Res Econ. 43:573–590. doi:10.1007/s10640-008-9251-7
Leal IC Jr, Garcia PAdA, D'Agosto MdA. 2012. A data envelopment analysis approach to choose transport modes based on eco-efficiency. Environ Dev Sust. 14:767–781. doi:10.1007/s10668-012-9352-x
Lima MAd, Ligo MAV, Pessoa MCPY, Neves MC, Carvalho ECd. 2010. Emissão de gases de efeito estufa na queima de resíduos agrícolas [Internet]. Relatórios de Referência. Brasília: Empresa Brasileira de Pesquisa Agropecuária – Embrapa. [cited 2014 Mar 25]. Available from: http://www.cetesb.sp.gov.br/userfiles/file/mudancasclimaticas/geesp/file/docs/publicacao/nacional/2_comunicacao_nacional/rr/agricultura/brasil_mcti_queima_residuos_agricolas.pdf.
Lima MAd, Ligo MAV, Pessoa MCPY, Luiz AJB, Neves MC, Maia AH. 2010. Emissão do metano do cutivo de arroz [Internet]. Relatório de Referência. Brasília: Empresa Brasileira de Pesquisa Agropecuária – Embrapa. [cited 2014 Mar 25]. Available from: http://www.cetesb.sp.gov.br/userfiles/file/mudancasclimaticas/geesp/file/docs/publicacao/nacional/2_comunicacao_nacional/rr/agricultura/brasil_mcti_arroz.pdf.
Lima MAd, Pessoa MCPY, Neves MC, Carvalho ECd. 2010. Emissões de metano por fermentação entérica e manejo de dejetos de animais [Internet]. Brasília: Empresa Brasileira de Pesquisa Agropecuária - Embrapa. [cited 2014 Mar 25]. Available from: http://www.cetesb.sp.gov.br/userfiles/file/mudancasclimaticas/geesp/file/docs/publicacao/nacional/2_comunicacao_nacional/rr/agricultura/brasil_mcti_fermentacao_enterica.pdf.
Lyytimäki J, Tapio P, Varho V, Söderman T. 2013. The use, non-use and misuse of indicators in sustainability assessment and communication. Int J Sustain Dev World Ecol. 20:385–393. doi:10.1080/13504509.2013.834524

McKinsey & Company. 2009. Caminhos para uma economia de baixa emissão de carbono no Brasil [Internet]. São Paulo. [cited 2014 Mar 25]. Available from: http://veja.abril.com.br/40anos/ambiente/pdf/relatorio-mckinsey.pdf.

Meadows DH, Meadows DL, Randers J, Behrens IIIWW. 1972. The limits to growth. New York (NY): Universe Books.

Montabon F, Sroufe R, Narasimhan R. 2007. An examination of corporate reporting, environmental management practices and firm performance. J Oper Manage. 25:998–1014. doi:10.1016/j.jom.2006.10.003

Munda G. 2005. "Measuring sustainability": a multi-criterion framework. Environ. Dev. Sustain. 7:117–134. doi:10.1007/s10668-003-4713-0

Morse S, McNamara N, Acholo M, Okwoli B. 2001. Sustainability indicators: the problem of integration. Sust Dev. 9:1–15. doi:10.1002/sd.148

Picazo-Tadeo AJ, Beltrán-Esteve M, Gómez-Limón JA. 2012. Assessing eco-efficiency with directional distance functions. Eur J Oper Res. 220:798–809. doi:10.1016/j.ejor.2012.02.025

Pittman RW. 1983. Multilateral productivity comparisons with undesirable outputs. Econ J. 93:883–891. doi:10.2307/2232753

Qiu H, Zhu W, Wang H, Cheng X. 2007. Analysis and design of agricultural sustainability indicators system. Agri Sci China. 6:475–486. doi:10.1016/S1671-2927(07)60072-8

Reig-Martínez E, Picazo-Tadeo A, Hernández-Sancho F. 2001. The calculation of shadow prices for industrial wastes using distance functions: an analysis for Spanish ceramic pavements firms. Int J Prod Econ. 69:277–285. doi:10.1016/S0925-5273(00)00018-9

Scheel H. 2001. Undesirable outputs in efficiency valuations. Eur J Oper Res. 132:400–410. doi:10.1016/S0377-2217(00)00160-0

Seuring S, Gold S. 2013. Sustainability management beyond corporate boundaries: from stakeholders to performance. J Clean Prod. 56:1–6. doi:10.1016/j.jclepro.2012.11.033

Shephard RW. 1954. Cost and production functions. Nav Res Log Quart. 1:171.

Speelman EN, López-Ridaura S, Colomer NA, Astier M, Masera OR. 2007. Ten years of sustainability evaluation using the MESMIS framework: lessons learned from its application in 28 Latin American case studies. Int J Sustain Dev World Ecol. 14:345–361. doi:10.1080/13504500709469735

Swinton JR. 1998. At what cost do we reduce pollution? Shadow prices of SO_2 emissions. Energ J. 19:63–83. 10.5547/ISSN0195-6574-EJ-Vol19-No4-3

Tyteca D. 1996. On the measurement of the environmental performance of firms – a literature review and a productive efficiency perspective. J Environ Manage. 46:281–308. doi:10.1006/jema.1996.0022

WCED. 1987. Report of the World Commission on Environment and Development: Our Common Future. United Nations World Commission on Environment and Development – WCED.